

ACCURACY OF PIEZOELECTRIC PEDOMETER AND ACCELEROMETER STEP COUNTS

Joana Cruz,^{1,2} Dina Brooks,³ Alda Marques^{1,2}

¹Lab 3R – Respiratory Research and Rehabilitation Laboratory, School of Health Sciences,
University of Aveiro (ESSUA), Aveiro, Portugal

²Center for Health Technology and Services Research (CINTESIS), School of Health Sciences,
University of Aveiro (ESSUA), Aveiro, Portugal

³Rehabilitation Science Institute and Department of Physical Therapy, University of Toronto,
Toronto, Ontario, Canada

Congresses: Part of the results of the present study were presented in a Poster Discussion session of the 25th European Respiratory Society (ERS) International Congress in Amsterdam, Netherlands (26-30 September 2015).

Funding: This work was supported by the Fundação para a Ciência e a Tecnologia (FCT) under grant number SFRH/BD/81328/2011.

Conflicts of interest: The authors report no conflicts of interest.

Acknowledgements: The authors gratefully acknowledge all the volunteers for participating in the study.

Corresponding author: Alda Marques, amarques@ua.pt, Telephone: 00351 234 372 462

Lab 3R – Respiratory Research and Rehabilitation Laboratory, School of Health Sciences of the University of Aveiro (ESSUA), Campus Universitário de Santiago, Agras do Crasto, Edifício 30, 3810-193 Aveiro (Portugal)

ABSTRACT

BACKGROUND: This study aimed to: assess step-count accuracy of a piezoelectric pedometer (Yamax PW/EX-510), when worn at different body parts, and a triaxial accelerometer (GT3X+); compare device accuracy; and identify the preferred location(s) to wear a pedometer.

METHODS: Sixty-three healthy adults (45.8 ± 20.6 years old) wore 7 pedometers (neck, lateral right and left of the waist, front right and left of the waist, front pockets of the trousers) and 1 accelerometer (over the right hip), while walking 120m at slow, self-preferred/normal and fast paces. Steps were recorded. Participants identified their preferred location(s) to wear the pedometer. Absolute percent error (APE) and Bland and Altman (BA) method were used to assess device accuracy (criterion measure: manual counts) and BA method for device comparisons.

RESULTS: Pedometer APE was below 3% at normal and fast paces despite wearing location, but higher at slow pace (4.5–9.1%). Pedometers were more accurate at the front waist and inside the pockets. Accelerometer APE was higher than pedometer APE ($P < 0.05$); nevertheless, limits of agreement between devices were relatively small. Preferred wearing locations were inside the front right ($n=25$) and left ($n=20$) pockets of the trousers.

CONCLUSION: Yamax PW/EX-510 pedometers may be preferable than GT3X+ accelerometers to count steps, as they provide more accurate results. These pedometers should be worn at the front right or left positions of the waist or inside the front pockets of the trousers.

Key words: actigraphy; dimensional measurement accuracy; exercise; walking.

INTRODUCTION:

Regular physical activity (PA) is associated with important health benefits¹ and may prevent the development and progression of chronic diseases (e.g., cardiovascular disease, chronic obstructive pulmonary disease [COPD])^{1,2}. Thus, improving PA levels of healthy and chronic disease populations has become a public health priority³.

Since walking is the most common type of exercise⁴, international PA recommendations using step-count goals have been developed^{5,6}. One simple strategy to monitor these goals is the use of pedometers⁷. Pedometers are simple and inexpensive motion devices that count steps taken and present them on real time, providing immediate feedback to the user. They have been used as a motivational tool to improve PA behaviours and in PA screening and assessment of interventions^{6,7}.

Numerous studies have evaluated the accuracy of diverse pedometers in measuring steps⁸⁻¹¹ and they concluded that accuracy was lower at slower speeds, particularly in pedometers using a spring-suspended horizontal lever arm mechanism^{8,11}. As these pedometers had to be worn in a vertical position on a belt/waistband, body composition and pedometer tilt could influence pedometer accuracy⁸. To overcome this problem, pedometers with a piezoelectric technology (e.g., Yamax PW/EX-510) were developed. These pedometers may be used in non-traditional wearing locations, e.g. inside the pockets or around the neck. Nevertheless, there are still few studies exploring the impact of wearing positions on accuracy of piezoelectric pedometers¹²⁻¹⁴. Furthermore, pedometers may have low acceptance when attached to certain body parts or clothing¹⁵ or when used in certain situations (e.g., when wearing a dress)¹⁶. This issue has been scarcely explored in previous validation studies, despite its importance to improve user acceptance¹⁵.

In addition to pedometers, the use of triaxial accelerometers (e.g., GT3X+) to objectively assess PA has increased in recent years¹⁷. Triaxial accelerometers are motion devices that measure acceleration in 3 planes during body movement¹⁸. Many accelerometers

have also a step-count function, though most of them do not provide feedback¹⁹. Hence, they are intended to measure PA rather than to motivate individuals to exercise. Accelerometers are often preferred in research and clinical settings because they provide more information than pedometers, e.g. frequency, duration and intensity of PA¹⁸. They have shown good validity with regard to activity counts and energy expenditure in healthy and chronic disease populations^{20, 21}; however, their step-count accuracy has not been extensively investigated, with most studies being conducted in the last 5 years²¹⁻²⁶. Assessment of accelerometer step-count accuracy along with pedometer accuracy is fundamental to enable comparisons among studies using different motion devices.

This study aimed to: (1) assess step-count accuracy of a piezoelectric pedometer (Yamax PW/EX-510), when worn at different body parts, and a triaxial accelerometer (GT3X+); (2) compare device accuracy; and (3) identify user's preferred location(s) to wear a pedometer.

METHODS:

Design

This prospective cross-sectional study was conducted as part of a larger study (www.clinicaltrials.gov, NCT02122614). Ethical approval was obtained from the Central Regional Health Administration (2011-02-28), Hospital Centre (34428) and National Data Protection Committee (9250/2012, 2012-11-06).

Participants

Sixty-three healthy adults volunteered to participate in the study. They were included if the following criteria were met: (1) ≥ 18 years old; (2) able to walk independently without a walking aid; and (3) able to understand the purpose and procedures of the study. Participants were excluded if they presented severe cardiovascular, neurological, respiratory, musculoskeletal or

psychiatric disorders or severe visual/hearing impairment. Written informed consent was obtained according to the *Declaration of Helsinki*.

Socio-demographic and anthropometric (height, weight) data were collected to characterise the sample. The performance of the Yamax PW/EX-510 pedometer (Yamasa Tokey Keiki Corporation, Tokyo, Japan) and the GT3X+ accelerometer (ActiGraph, Pensacola, FL) was then assessed.

Instruments

The Yamax PW/EX-510 is a lightweight pedometer with a triaxial sensor and a visual display to present on real time the estimated step counts, energy expenditure, fat burn, distance and activity time. For this study, only step counts were considered. This pedometer has an 11-step filter (i.e., if a person moves less than 11 steps and take about 5s without moving, those steps are not counted) to recognise actual walking activity and a 30-day and 30-week memory function that enables the user to recall steps. The user's weight and stride length must be entered before using the pedometer.

The GT3X+ accelerometer has also an embedded triaxial sensor that detects acceleration in 3 planes. After initialisation, the device collects and stores PA data which can be further downloaded and converted into time-stamped activity counts, step counts, energy expenditure and body postures, using specific software (Actilife – ActiGraph, Pensacola, FL). The accelerometer does not have a visual display to provide the user with real-time data.

Procedures

This study followed the international recommendations for pedometer testing¹⁸: (1) pedometers should be tested during walking at slow, moderate and fast paces; and (2) pedometer accuracy should be assessed by manually counting steps (criterion measure) over a 100- to 200-meter course and then comparing pedometer steps and manual counts. To perform the tests,

participants were required to use trousers with front side pockets and flat shoes (except flip-flops). They were instructed to walk 120m in a straight 20-meter corridor while wearing 7 pedometers and 1 accelerometer. Pedometers were worn simultaneously at different body parts: 1 around the neck suspended from a lanyard; 2 attached with a belt clip at the lateral right and left (midaxillary line) sides of the waist and 2 attached at the front right and left (midclavicular line) sides; 2 in the front (right and left) pockets of the trousers. Universal belt clips were used to attach the pedometers at the waist. Before data collection, one researcher entered participant's weight and stride length in each pedometer. Stride length was measured by asking patients to walk 10 steps in a straight corridor marked with a measuring tape and dividing the total distance per 10 (e.g., 6.0m/10 steps=0.60m). The accelerometer was worn on a waistband over the right hip, according to the manufacturer recommendations and the results from a recent study²⁶. It was initialised before data collection (30Hz) using ActiLife v6.7.2.

The test (i.e., walking 120m) was performed at 3 different paces in a random order: slow, self-preferred (normal) and fast pace. For slow pace, participants were asked to walk slowly as if they were taking a walk. For normal pace, participants were instructed to walk at their usual speed. For fast pace, they were asked to walk as if they were late to an appointment. Trials were repeated twice at two proximal occasions. All trials were recorded using video-recordings. One researcher counted every step taken during trials with a digital tally counter (criterion measure) and recorded trial duration using a stopwatch. At the end of each trial, the researcher registered step counts of each pedometer. Pedometers were then set to zero for the next trial. To ensure researcher blinding, manual counts were recorded before registering pedometer steps. Only in case of doubt the researcher signalled the trial of interest and reviewed the video-recording. As the accelerometer does not provide real time data, the researcher recorded the start time of each trial to allow its identification in the data downloaded. Data were downloaded in 1-by-1s epochs using Actilife v6.7.2.

After completing the tests, participants' opinion about the most and least preferred locations to wear a pedometer was collected. They could choose up to 3 wearing locations (without order of preference).

Statistical analysis

Descriptive statistics were conducted to characterise the sample. The average walking speed (trial 1) was calculated for each pace using the equation 1:

$$\text{Speed (km/h)} = 0.120 \text{ (km)} / \text{time (h)} \quad (1)$$

where 0.120km is the total distance walked and time is the duration of each trial.

Accuracy of pedometers and accelerometer was analysed by comparing their estimated steps with manual counts (trial 1) and consistency of measurement error was assessed by comparing the results of the same device on trials 1 and 2. The absolute percent error (APE) was calculated for each device at each walking pace as follows (equation 2):

$$\text{APE} = (|\text{device steps} - \text{observed steps}| / \text{observed steps}) * 100 \quad (2)$$

APE absolute value was used to avoid that positive and negative values cancelled each other out when calculating average APE. Values closer to zero indicated more accurate results and an APE below 3% has been considered acceptable^{9, 14}.

Normality of data was assessed with the Kolmogorov-Smirnov test. Differences in accuracy of devices were analysed with a repeated measures analysis of variance (ANOVA), for each walking pace. If a significant difference was detected ($P < 0.05$), post-hoc analyses were conducted. Consistency of measurement error was assessed using paired samples t-tests. APE was used instead of step counts to account for individual variability (i.e., number of steps may vary among individuals even in a well-controlled environment).

The Bland and Altman (BA) method²⁷ was used to assess agreement between estimated steps and manual counts (trial 1). Mean of the differences and tight agreement intervals around 0 suggested more accurate results. The BA method was also used to examine agreement

between pedometer- and accelerometer-estimated steps. Positive values indicated that pedometer presented higher values than accelerometer.

Data concerning participants' most and least preferred locations to wear a pedometer were converted into frequencies. When participants identified more than 1 preferred location, all answers were considered.

Statistical analyses were performed using SPSS v20.0 (IBM Corp., Armonk, NY) and GraphPad Prism v5.0 (GraphPad Inc., La Jolla, CA, USA).

RESULTS:

Participants

Participants had a mean age of 45.8 ± 20.6 years (range 20-86) and body mass index of $25.2 \pm 4.3 \text{ kg/m}^2$, mostly female ($n=42$, 66.7%). The average speed performed in slow, normal and fast paces was $3.3 \pm 0.6 \text{ km/h}$, $4.4 \pm 0.7 \text{ km/h}$ and $5.5 \pm 0.7 \text{ km/h}$, respectively. The number of steps recorded manually and through pedometers and accelerometer is presented in Table I.

(table I)

Device accuracy

Absolute percent error. Table II presents the APE of pedometers and accelerometer on trials 1 and 2. On trial 1, the mean APE of pedometers was below 3% at normal and fast paces, despite wearing location. The performance was poorer at slow pace (mean APE > 4%). When comparing locations, accuracy was improved (i.e., mean and standard deviation were the smallest) for pedometers located at the front right and left of the waist, at all paces (Table II). Pedometers inside the pockets also showed a high performance, with the pedometer of the left pocket presenting the lowest APE at slow pace ($4.5 \pm 7.7\%$). Despite that, differences among pedometer APE were only significant between pedometers worn around the neck and attached to the front left of the waist, the latter presenting a lower APE ($1.9 \pm 2.1\%$ vs. $1.2 \pm 1.4\%$, $P=0.006$).

The accelerometer presented a high APE, ranging from $16.8 \pm 19.4\%$ at slow pace to $3.9 \pm 2.9\%$ at fast pace.

Regarding consistency of measurement error, no significant differences were found between APEs of pedometers ($P > 0.05$), irrespective of wearing location. The same results were found for the accelerometer ($P > 0.05$, Table II).

(table II)

Bland and Altman method. Table III presents the mean of the differences between manual counts and device-estimated steps and the LoA. An excellent level of agreement was found for all pedometers at normal and fast paces, except for the pedometer around the neck which presented poorer agreement (i.e., higher mean difference and wider LoA). At slow pace, the mean difference between manual counts and pedometer-estimated steps was high (from -6.7 to -19.8 steps) and the LoA were wide, despite wearing location. Overall, better agreement results were found for pedometers located at the front right and left of the waist and inside the pockets.

The accelerometer showed the highest mean of the differences and the widest LoA, at all walking paces (Table III).

(table III)

Comparison between devices

When comparing the two devices, the accelerometer presented a significantly higher APE than pedometers, regardless of wearing location ($0.001 < P < 0.043$, Table II). The accelerometer recorded a lower number of steps than pedometers, with the mean of the differences ranging from 19.7 to 29.2 steps at slow, 5.7 to 7.7 steps at normal, and 3.5 to 5.8 steps at fast pace (Table IV). Even though, the LoA were relatively small at normal and fast paces.

(table IV)

Pedometer preferred locations

According to participants' opinion, the best locations to wear the pedometer were inside the right (n=25) and left (n=20) pockets of the trousers (Figure 1). The neck was reported both as one of the most (n=17) and least (n=15) preferred locations. Other least preferred locations were the lateral right and left positions of the waist (n=21 each) and the front right and left positions of the waist (n=16 each).

(figure 1)

DISCUSSION:

Pedometers Yamax PW/EX-510 were highly accurate in quantifying steps at normal and fast walking paces, but less accurate at slow pace. Pedometers worn at the front right and left of the waist and inside the pockets of the trousers were the most accurate. The latter was also the most preferred location to wear the pedometer. The GT3X+ accelerometer underestimated the steps when compared to manually-counted and pedometer steps. Findings support the use of pedometers for measuring ambulatory activity using step counts.

Accuracy of pedometers was low at slow pace, despite wearing location. Similar results have been described in validation studies using other piezoelectric pedometers^{12, 14}, suggesting that caution should be taken when using this type of technology in slow walking populations (e.g., older adults²⁸ and patients with neurological disorders²⁹). Nevertheless, piezoelectric pedometers have shown lower measurement errors than those using a spring-suspended lever arm mechanism, particularly at slower speeds^{8, 11}. Thus, pedometers with a piezoelectric mechanism should be preferred particularly when used by individuals who naturally ambulate at slower speeds. In controlled conditions, a 3% is frequently considered an acceptable measurement error^{9, 14}. Other studies have suggested that a maximum error of 5%^{12, 30} or 10%⁹ can be accepted for slower speeds. In this study, the average measurement error of pedometers was approximately 4.5-9.1%, thus they may be considered fairly accurate.

Pedometers were more accurate when worn at the front right and left of the waist and inside the pockets. These results were consistent among trials. Therefore, individuals should be provided with these two wearing options when using Yamax PW/EX-510 pedometers. Since some individuals have reported difficulties in deciding where to use the pedometer in certain situations (e.g., when using clothing without pockets)¹⁶, this finding may improve users' acceptance of pedometers. Furthermore, pockets were identified as a preferred location to wear the pedometer, thus this option may enhance pedometer use in daily living.

Pedometer worn around the neck was reported as both one of the most and least preferred locations. Although this is one of the manufacturers' recommended positions, results suggest that it may not be advisable since it was one of the locations with lower accuracy and agreement results. Reasons for these findings are not clear, however, it is possible that lack or excess of movement of the upper body during walking may have produced over- or under-oscillation of the pedometer, leading to higher measurement error. Previous validation studies using other piezoelectric pedometer brand have shown opposite findings, with pedometers around the neck providing the most accurate results^{12, 13}. This finding reinforces the need to test different pedometer models before using them, as recommended in international guidelines¹⁸.

The GT3X+ accelerometer provided poorer accuracy and agreement results than pedometers, although differences between devices and LoA were relatively small at normal and fast paces. Previous research supports these findings. Studies conducted in specific populations (i.e., pregnant women, overweight and obese adults, older adults with/without walking aids) have shown that pedometers (either with a piezoelectric or a lever arm mechanism) present higher step-count accuracy results than the GT3X+²²⁻²⁵, particularly when walking at slower speeds^{24, 25}. Therefore, caution must be taken when comparing step counts of studies that have employed different types of motion devices, since their findings may differ. Likewise, the choice of the motion device should be based on a number of factors, including:

- (1) Need for PA feedback – since pedometers provide feedback to the user, they may be more appropriate in self-monitoring interventions^{17, 18}. Conversely, if individuals must be

blinded, then accelerometers may be chosen as most of them do not provide this feedback function¹⁹;

- (2) Type of outcomes – accelerometers capture the frequency, duration and intensity of human movement, providing a more detailed analysis of daily PA^{17, 18}. Hence, they may be valuable in PA screening or assessment of PA interventions;
- (3) Cost – pedometers may be preferred to accelerometers in simple studies measuring only step counts, due to their lower cost¹⁸ and high accuracy (as found in the present study).

Strengths and limitations

This study has several strengths that should be acknowledged. Overground walking was chosen instead of treadmill walking to reflect daily ambulatory activity. Nevertheless, it was not possible to control walking speed throughout the tests. Participants' opinion about the most and least preferred locations to wear the pedometer was a novel and important finding, as it may influence people's adherence in using pedometers on a daily basis. Finally, validation of Yamax PW/EX-510 pedometer was innovative, since previous studies validating piezoelectric pedometers have been mostly limited to Omron models^{12-14, 31, 32}. This pedometer has additional features that may be valuable in motivating individuals to be more physically active (e.g., 30-day and 30-week memory function). This should be further explored.

This study had also several limitations. One limitation concerns to the fact that only step counts were considered. Since both devices are able to provide additional parameters, these should be validated in future research. The context of validation tests (i.e., controlled conditions) was another limitation. Tests conducted under free-living conditions are warranted to fully capture the potential of motion devices to detect human activity. Lastly, all tests were performed in healthy adults which may limit the generalisability of findings. Nevertheless, previous validation studies conducted in healthy and chronic disease populations concluded that pedometer accuracy was similar between samples when walking at different speeds^{33, 34}.

CONCLUSIONS:

Findings suggest that Yamax PW/EX-510 pedometers may be preferable than GT3X+ accelerometers to count steps, as they provide more accurate results. These pedometers should be worn at the front right or left positions of the waist or inside the front pockets of the trousers. The latter was considered the most preferred location to wear the pedometer.

REFERENCES:

1. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *Can Med Assoc J.* 2006;174(6):801-9.
2. Esteban C, Quintana JM, Aburto M, Moraza J, Egurrola M, Perez-Izquierdo J, et al. Impact of changes in physical activity on health-related quality of life among patients with COPD. *Eur Respir J.* 2010;36(2):292-300.
3. World Health Organization. Global recommendations on physical activity for health. Geneva: WHO Library Cataloguing-in-Publication Data; 2010.
4. Hootman JM, Macera CA, Ainsworth BE, Martin M, Addy CL, Blair SN. Association among Physical Activity Level, Cardiorespiratory Fitness, and Risk of Musculoskeletal Injury. *Am J Epidemiol.* 2001;154(3):251-8.
5. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc.* 2011;43(7):1334-59.
6. Tudor-Locke C, Bassett DR, Jr. How many steps/day are enough? Preliminary pedometer indices for public health. *Sports Med.* 2004;34(1):1-8.
7. Bravata DM, Smith-Spangler C, Sundaram V, Gienger AL, Lin N, Lewis R, et al. Using pedometers to increase physical activity and improve health: a systematic review. *JAMA.* 2007;298(19):2296-304.
8. Crouter SE, Schneider PL, Bassett DR, Jr. Spring-levered versus piezo-electric pedometer accuracy in overweight and obese adults. *Med Sci Sports Exerc.* 2005;37(10):1673-9.
9. Crouter SE, Schneider PL, Karabulut M, Bassett DR, Jr. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc.* 2003;35(8):1455-60.

10. Le Masurier GC, Lee SM, Tudor-Locke C. Motion sensor accuracy under controlled and free-living conditions. *Med Sci Sports Exerc.* 2004;36(5):905-10.
11. Melanson EL, Knoll JR, Bell ML, Donahoo WT, Hill JO, Nysse LJ, et al. Commercially available pedometers: considerations for accurate step counting. *Prev Med.* 2004;39(2):361-8.
12. De Cocker KA, De Meyer J, De Bourdeaudhuij IM, Cardon GM. Non-traditional wearing positions of pedometers: Validity and reliability of the Omron HJ-203-ED pedometer under controlled and free-living conditions. *J Sci Med Sport.* 2012;15(5):418-24.
13. Hasson RE, Haller J, Pober DM, Staudenmayer J, Freedson PS. Validity of the Omron HJ-112 Pedometer during Treadmill Walking. *Med Sci Sports Exerc.* 2009;41(4):805-9
10.1249/MSS.0b013e31818d9fc2.
14. Holbrook EA, Barreira TV, Kang M. Validity and Reliability of Omron Pedometers for Prescribed and Self-Paced Walking. *Med Sci Sports Exerc.* 2009;41(3):670-4.
15. de Bruin ED, Hartmann A, Uebelhart D, Murer K, Zijlstra W. Wearable systems for monitoring mobility-related activities in older people: a systematic review. *Clin Rehabil.* 2008;22(10-11):878-95.
16. Gardner PJ, Campagna PD. Pedometers as measurement tools and motivational devices: new insights for researchers and practitioners. *Health Promot Pract.* 2011;12(1):55-62.
17. Trost SG, O'Neil M. Clinical use of objective measures of physical activity. *Br J Sports Med.* 2014;48(3):178-81.
18. Strath SJ, Kaminsky LA, Ainsworth BE, Ekelund U, Freedson PS, Gary RA, et al. Guide to the Assessment of Physical Activity: Clinical and Research Applications: A Scientific Statement From the American Heart Association. *Circulation.* 2013;128:2259-79.
19. Bassett DR, John D. Use of pedometers and accelerometers in clinical populations: validity and reliability issues. *Phys Ther Rev.* 2010;15(3):135-42.

20. Santos-Lozano A, Santin-Medeiros F, Cardon G, Torres-Luque G, Bailon R, Bergmeir C, et al. Actigraph GT3X: validation and determination of physical activity intensity cut points. *Int J Sports Med.* 2013;34(11):975-82.
21. Van Remoortel H, Giavedoni S, Raste Y, Burtin C, Louvaris Z, Gimeno-Santos E, et al. Validity of activity monitors in health and chronic disease: a systematic review. *Int J Behav Nutr Phys Act.* 2012;9(1):84.
22. Barreira TV, Brouillette RM, Foil HC, Keller JN, Tudor-Locke C. Comparison of older adults' steps per day using NL-1000 pedometer and two GT3X+ accelerometer filters. *J Aging Phys Act.* 2013;21(4):402-16.
23. Barreira TV, Tudor-Locke C, Champagne CM, Broyles ST, Johnson WD, Katzmarzyk PT. Comparison of GT3X accelerometer and YAMAX pedometer steps/day in a free-living sample of overweight and obese adults. *J Phys Act Health.* 2013;10(2):263-70.
24. Connolly CP, Coe DP, Kendrick JM, Bassett DR, Jr., Thompson DL. Accuracy of physical activity monitors in pregnant women. *Med Sci Sports Exerc.* 2011;43(6):1100-5.
25. Webber SC, Magill SM, Schafer JL, Wilson KC. GT3X+ accelerometer, Yamax pedometer and SC-StepMX pedometer step count accuracy in community-dwelling older adults. *J Aging Phys Act.* 2014;22(3):334-41.
26. Tudor-Locke C, Barreira TV, Schuna JM, Jr. Comparison of step outputs for waist and wrist accelerometer attachment sites. *Med Sci Sports Exerc.* 2015;47(4):839-42.
27. Bland MJ, Altman DG. Statistical Methods for Assessing Agreement between Two Methods of Clinical Measurement. *Lancet.* 1986;327(8476):307-10.
28. Prince F, Corriveau H, Hébert R, Winter DA. Gait in the elderly. *Gait Posture.* 1997;5(2):128-35.
29. Busse ME, Wiles CM, van Deursen RWM. Community walking activity in neurological disorders with leg weakness. *J Neurol Neurosurg Psychiatry.* 2006;77(3):359-62.
30. Vincent SD, Sidman CL. Determining Measurement Error in Digital Pedometers. *Meas Phys Educ Exerc Sci.* 2003;7(1):19-24.

31. Wallmann-Sperlich B, Froboese I, Reed JL, Mathes S, Sperlich B. How accurate are Omron X-HJ-304-E and Yamax SW-700/701 pedometers at different speeds and various inclinations? *J Sports Med Phys Fitness*. 2015;55(1-2):113-7.
32. Zhu W, Lee M. Invariance of wearing location of Omron-BI pedometers: a validation study. *J Phys Act Health*. 2010;7(6):706-17.
33. Furlanetto KC, Bisca GW, Oldenberg N, Sant'Anna TJ, Morakami FK, Camillo CA, et al. Step Counting and Energy Expenditure Estimation in Patients With Chronic Obstructive Pulmonary Disease and Healthy Elderly: Accuracy of 2 Motion Sensors. *Arch Phys Med Rehabil*. 2010;91(2):261-7.
34. Turner LJ, Houchen L, Williams J, Singh SJ. Reliability of pedometers to measure step counts in patients with chronic respiratory disease. *J Cardiopulm Rehabil Prev*. 2012;32(5):284-91.

TITLES OF TABLES:

Table I. Number of steps collected manually and through the pedometers (worn at different body parts) and the accelerometer, at 3 walking paces.

	Slow pace	Normal pace	Fast pace
Manual count (steps)	215.0±23.8	189.2±22.2	172.2±20.2
Pedometer (steps)			
Neck	196.6±37.1	185.4±19.6	168.8±18.1
Lateral right	195.3±36.0	186.8±20.7	169.9±19.1
Front right	201.5±32.3	186.8±20.6	170.1±18.7
Right pocket	202.2±31.6	187.1±20.5	170.1±18.7
Lateral left	200.6±34.5	186.2±21.1	169.4±18.6
Front left	202.4±29.9	187.0±20.9	169.9±19.5
Left pocket	206.8±20.7	186.9±19.7	170.5±19.9
Accelerometer (steps)	175.5±38.7	179.1±16.9	164.5±15.3

Table II. Absolute percent error (APE) of steps registered by the pedometers worn at different body parts and the accelerometer, at 3 walking paces (results from trials 1 and 2).

	Slow pace		Normal pace		Fast pace	
	APE (%)		APE (%)		APE (%)	
	mean, SD		mean, SD		mean, SD	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Pedometer						
Neck	9.0±17.2	8.8±18.1	1.9±2.1 ^a	1.8±1.8	1.9±1.8	1.9±1.8
Lateral right	9.1±16.5	7.0±13.7	1.6±1.5	1.9±2.5	1.5±1.5	1.8±2.3
Front right	6.8±12.9	5.7±12.1	1.3±1.3	1.5±2.4	1.3±1.4	1.4±2.1
Right pocket	6.3±12.7	5.7±14.7	1.2±1.7	1.6±3.4	1.8±1.9	1.4±1.8
Lateral left	6.9±14.1	6.2±12.3	1.9±3.4	3.1±11.7	1.6±2.3	1.4±1.9
Front left	5.8±11.0	5.3±12.1	1.2±1.4 ^a	1.3±2.3	1.4±1.9	1.2±1.7
Left pocket	4.5±7.7	3.4±9.1	1.7±2.9	1.8±2.3	1.7±1.9	1.7±2.3
Accelerometer	16.8±19.4 ^b	15.7±19.4	4.6±2.6 ^b	4.6±3.1	3.9±2.9 ^b	3.8±3.5

^aDifferences between APE of the pedometers were significant ($P=0.006$). ^bDifferences between the APE of all pedometers and the accelerometer on trial 1 were significant at slow pace ($0.001 < P < 0.043$), and at normal and fast paces ($P < 0.001$). Abbreviations: APE, absolute percent error; SD, standard deviation.

Table III. Mean of the differences between manually-counted and device-estimated steps and limits of agreement, at 3 walking paces.

	Slow pace		Normal pace		Fast pace	
	Mean _{diff} (steps)	LoA (steps)	Mean _{diff} (steps)	LoA (steps)	Mean _{diff} (steps)	LoA (steps)
Pedometer						
Neck	-18.5	-100.6 – 63.7	-3.8	-13.2 – 5.6	-3.4	-10.4 – 3.6
Lateral right	-19.8	-94.9 – 55.3	-2.3	-9.6 – 5.0	-2.3	-8.3 – 3.7
Front right	-13.5	-71.4 – 44.4	-2.4	-8.1 – 3.3	-2.1	-7.9 – 3.7
Right pocket	-11.2	-69.3 – 46.8	-1.1	-9.2 – 6.9	-1.1	-10.3 – 8.1
Lateral left	-14.4	-75.3 – 46.4	-3.0	-16.4 – 10.4	-2.9	-11.9 – 6.2
Front left	-12.7	-61.9 – 36.5	-2.2	-8.1 – 3.7	-2.2	-9.6 – 5.1
Left pocket	-6.7	-48.4 – 35.0	-1.4	-15.6 – 12.8	-1.6	-9.5 – 6.3
Accelerometer	-38.5	-137.4 – 60.4	-9.1	-21.2 – 3.1	-6.8	-19.1 – 5.4

Abbreviations: Mean_{diff}, mean of the differences (i.e., observed steps – device steps); LoA, limits of agreement.

Table IV. Mean of the differences between pedometer and accelerometer step counts and limits of agreement, at 3 walking paces.

	Accelerometer					
	Slow pace		Normal pace		Fast pace	
	Mean _{diff}	LoA (steps)	Mean _{diff}	LoA (steps)	Mean _{diff}	LoA (steps)
	(steps)		(steps)		(steps)	
Pedometer						
Neck	21.6	-76.4 – 119.5	5.7	-4.2 – 15.5	3.5	-5.7 – 12.7
Lateral right	19.7	-60.7 – 100.0	6.9	-4.6 – 18.4	4.7	-7.0 – 16.2
Front right	26.6	-59.6 – 112.7	6.8	-3.6 – 17.2	4.9	-4.9 – 14.7
Right pocket	26.2	-50.8 – 103.2	7.7	-4.0 – 19.3	5.8	-7.4 – 18.9
Lateral left	26.3	-64.2 – 116.8	6.2	-8.8 – 21.1	4.1	-5.7 – 13.8
Front left	28.3	-63.1 – 119.7	7.0	-3.6 – 17.6	4.7	-5.2 – 14.5
Left pocket	29.2	-37.5 – 95.9	7.4	-4.7 – 19.4	5.4	-7.7 – 18.5

Abbreviations: Mean_{diff}, mean of the differences (i.e., pedometer steps – accelerometer steps);

LoA, limits of agreement.

TITLES OF FIGURES:

Figure 1. Participants' opinion about the most and least preferred locations to wear the pedometer (participants could choose more than 1 preferred location up to 3, without order of preference).

